ECL 201

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DESIGN OF AN IMPROVED AIRCRAFT SEAT

This case study deals with the design and development of an airline passenger seat which emphasizes safety and comfort. With minor modifications the seat will also be applicable to other transportation facilities where high acceleration levels are possible during accidents.

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1. INTRODUCTION

NASA Ames Research Center

The seat's development was supervised by the National Aeronautics and Space Administration (NASA) which is a government agency devoted to the research and development of projects associated with aeronautics and astronautics. NASA is divided into many divisions, all of which come under the general supervision of NASA Headquarters in Washington, D. C. (Figure 1.1). Within each division is a group of subdivisions as shown in the block diagram of NASA Ames Research Center (Figure 1.2). The detailed design and prototype construction was performed by Stencel Aero Engineering Corporation under contract to NASA. NASA's primary role was design, guidance, and evaluation of the project.

Survival Criteria

Reducing the number of fatalities attributable to aircraft accidents has been an elusive goal since the beginning of aviation. In today's era of commercial aviation, passenger protection is rapidly becoming a critical issue due to the large numbers of people flying in transsonic aircraft. With increasing public awareness focusing on consumer safety and product liability, the National Aeronautics and Space Administration in 1966 initiated a study to analyze and propose modifications to existing aircraft. Later that year, Stencel Aero Engineering Corporation of Asheville, North Carolina, was awarded NASA Contract NASw-1530 to formulate conceptual designs for the "improvement of human survival in civilian aircraft emergencies." Funding for this contract was procured under the Life Support and Protective Systems subprogram of the Human Factors System program, a line item of the 1966 Congressional authorization to NASA.

Stencel Aero is a small engineering company having approximately thirty engineers on its staff. Virtually all of Stencel's previous contracts had been in the field of military applications. In particular, their design work centered upon the development of explosive-type ejection seats and related equipment commonly used in military aircraft.

For their conceptual study, Stencel used statistical data compiled by the Federal Aviation Agency. Definition of the most severe environments to which humans could be subjected and still survive were abstracted from the FAA-Civil Aeromedical Research Institute, from NASA research reports, and from tests made by the Flight Safety Foundation. These statistics indicated that in nearly 70% of all aircraft accidents, the damage to the airframe was such that the fuselage remained sufficiently intact for human survival. For the purposes of

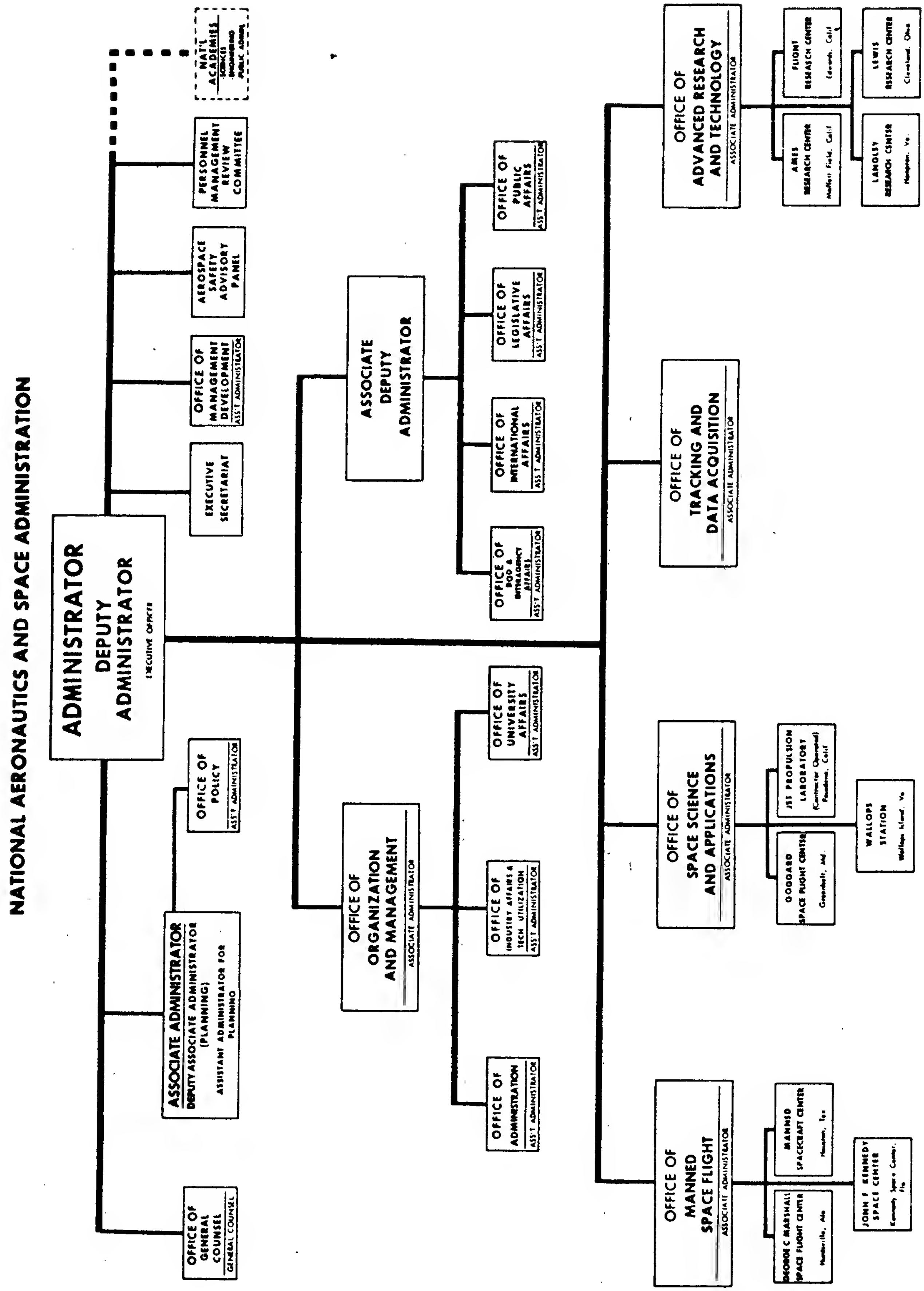


Figure 1.1 - NASA Administration

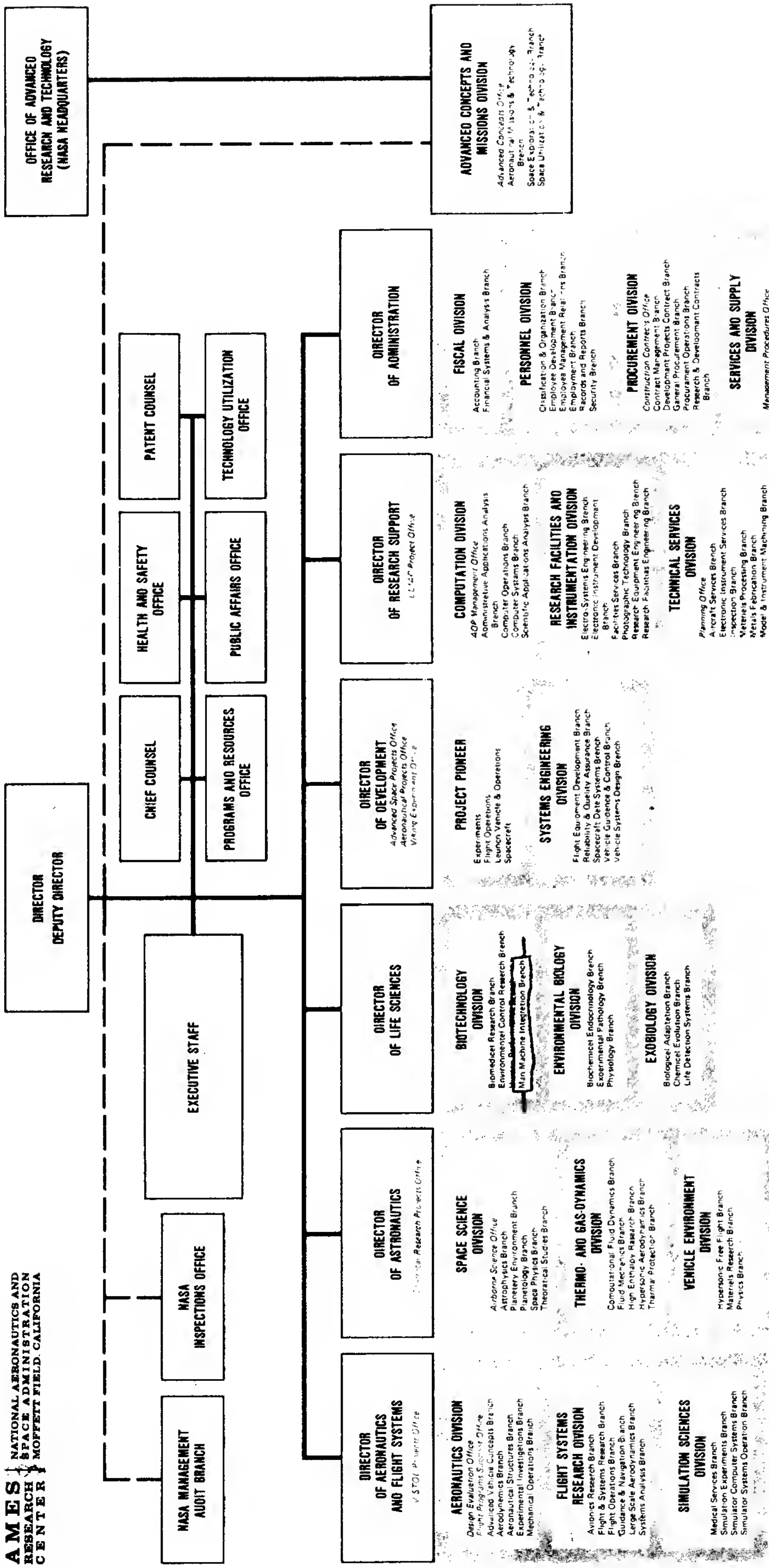


Figure 1.2 - NASA Ames Research Center

their analysis, Stencel assumed that any aircraft fires would be suppressed and that the passengers would be protected from smoke and fumes, and then evacuated. Based on these assumptions, it was evident that two specific design limits had to be determined. The first was the aircraft's structural capability, and the second was the required structural capability of the occupant seat.

Assuming the fuselage structure was not to be modified, Stencel engineers estimated the maximum vertical and horizontal tolerances which the airframe could withstand without disintegration. To obtain the amount of deceleration attenuation the occupant seat had to provide, the maximum occupant survival tolerance was also determined. The results of these analyses were graphed as shown in Figure 1.3.

It should be noted that the airframe has greater capability in the horizontal direction than in the vertical direction. This is attributed to various sliding conditions on impact. Sliding permits a longer horizontal deceleration distance whereas in the vertical direction, diametric crushing of the aircraft fuselage is the only means of attenuation. Inside the aircraft, occupant deceleration distances are limited by surrounding seats, by the cockpit envelope, or by the distance from the bottom of the seat to the floor. The passenger must be decelerated within these limits to avoid a fatal impact injury.

From the aircraft structure capability data shown in Figure 1.3, it was possible to define the boundary between a survivable and insurvivable accident as a function of flight velocity and impact angle. This was graphed as shown in Figure 1.4, which correlated quite well with documented aircraft accident statistics.

Reviews of existing crash data indicated that 70 to 80 percent of all aircraft injuries were a result of face or head impacts caused by the flailing of the head and upper torso. To aid in designing a less injurious passenger enclosure, tests were made of fifth and ninety-fifth percentile passengers accelerated forward over a tight safety belt. The motions of the passengers under a one g acceleration were recorded as shown in Figure 1.5. Two conclusions were reached from these tests. First, allowing excess seating clearance for unrestrained torso motion was neither economically feasible nor safe for the passenger. From previous accident reports, the fore and aft whiplash motions developed in such a restraint system were quite serious. Second, head and torso restraint was a safe and practical way to prevent impacts within the existing aircraft passenger envelope. While restraint of the legs and arms would also have been desirable, possible injury to these

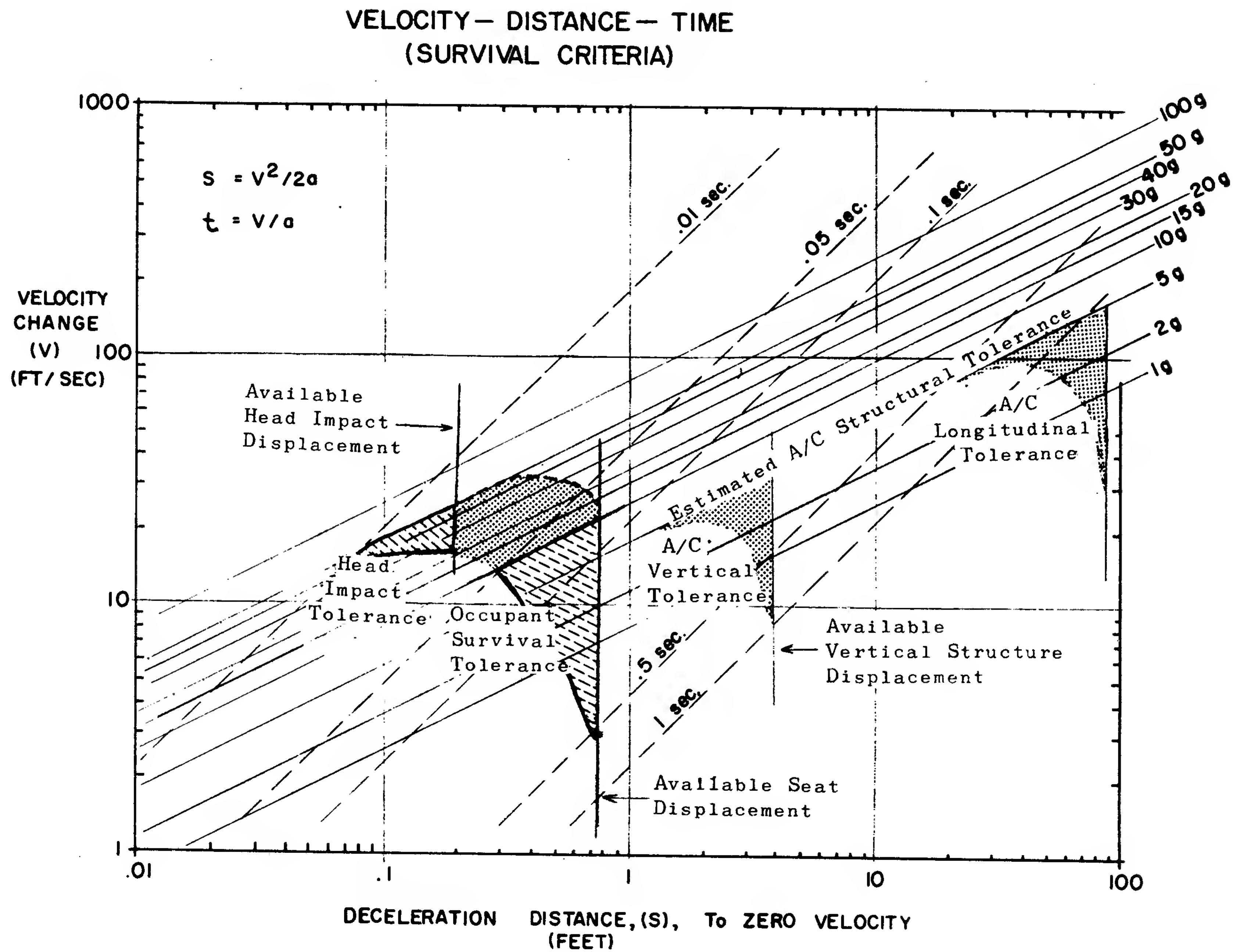


Figure 1.3 - Occupant Survival Tolerance

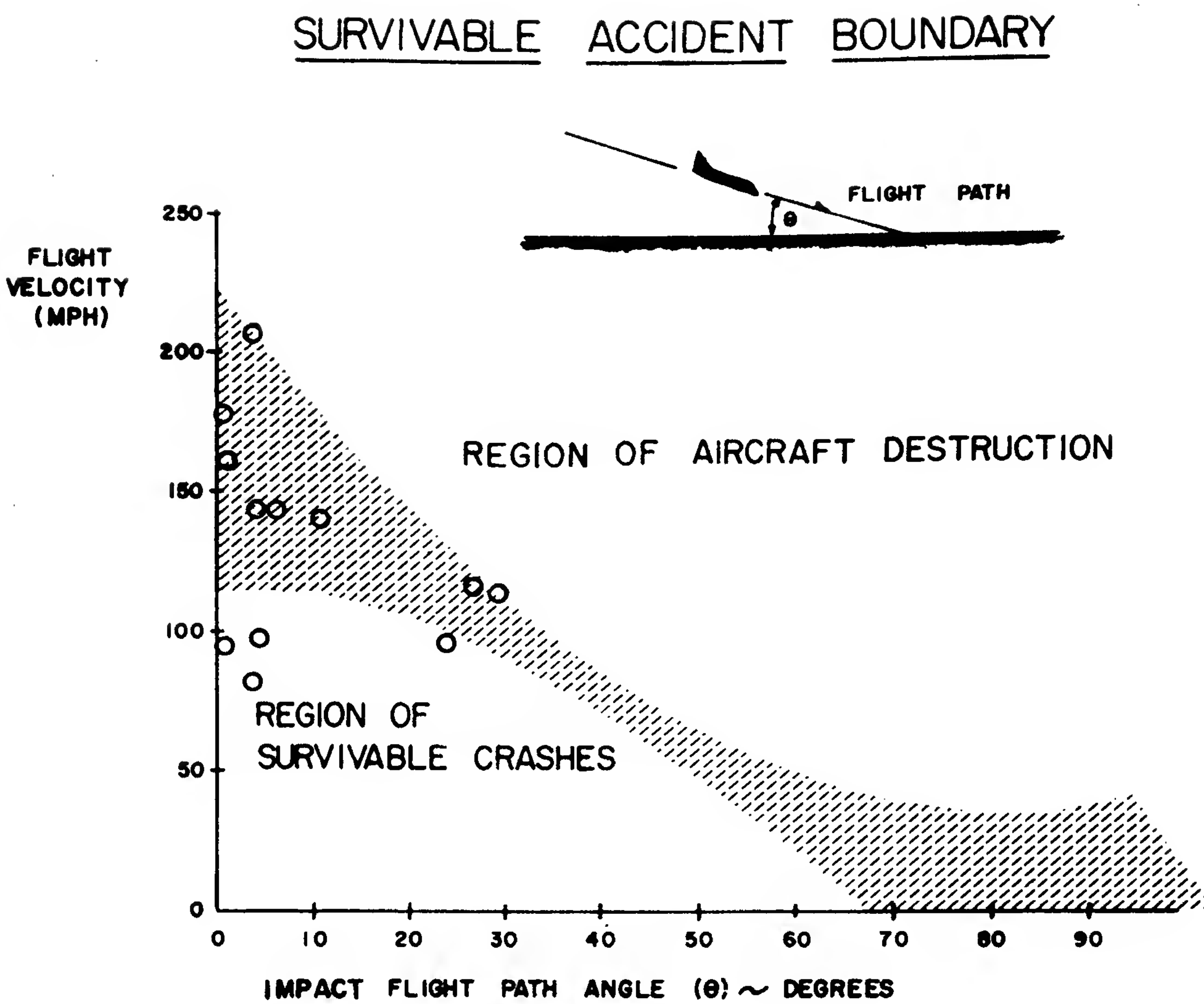
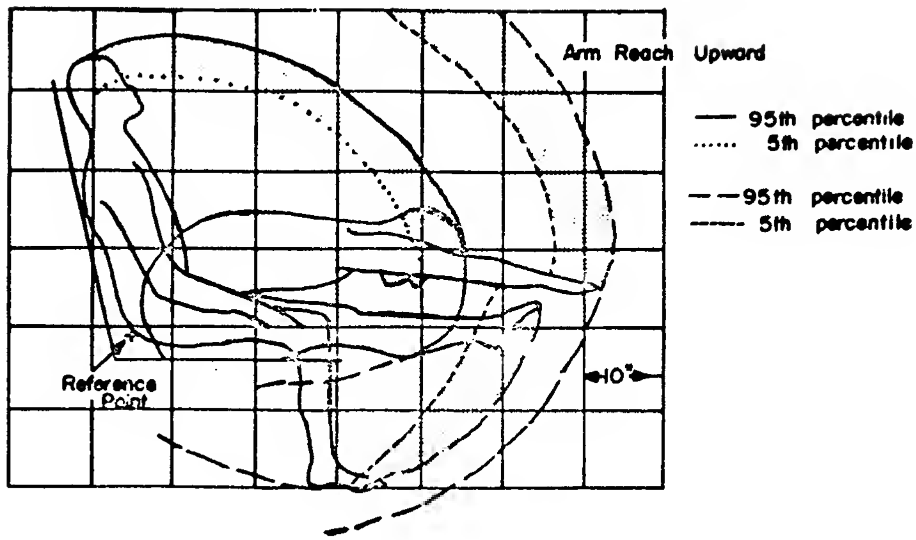


Figure 1.4 - Accident Survival Boundry

RESTRAINED HUMAN IMPACT ENVELOPE



(a)

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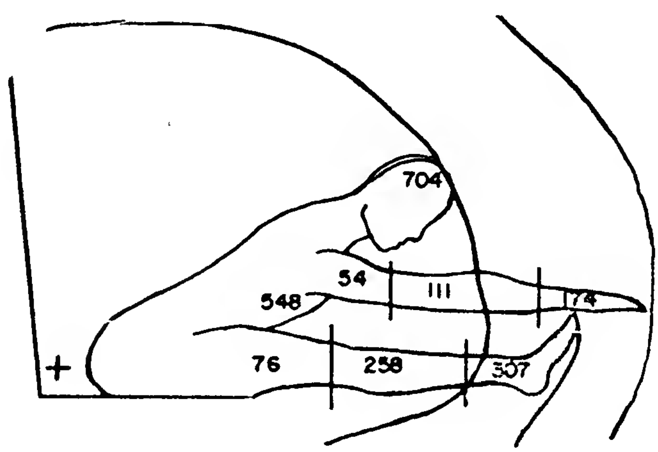
RESTRAINED HUMAN INJURY AREAS
LIGHT AIRCRAFT CRASHES



(b)

Figure 1.5 - Passenger Motion

areas is not usually fatal. The major problem in implementing such a system was to devise a mechanism both practical and comfortable.

2. CONCEPTUAL DEVELOPMENT

The conclusions which Stencel reached led to a concentration of effort in two main areas, internal and external to the aircraft. Stencel's preliminary report to NASA stated, "Internal survival improvements contain design objectives for occupant seating and restraint; external survival improvements are directed at methods for occupant or aircraft kinetic energy reduction prior to impact."

The methods which were analyzed for application are shown in Figure 2.1. These were divided into three modes of flight: take-off, in-flight, and landing. Those methods which were judged economically reasonable and operationally practical were indicated by a circular mark.

Two schemes for external aircraft velocity reduction were developed from this analysis. The first, interior pod recovery, involved extracting a passenger pod from a disabled aircraft and slowing its descent by parachute. The second, transport fuselage recovery, was based on using a parachute-retrorocket system attached to the fuselage to slow the aircraft's impact velocity. In order to make this system practical from the standpoint of parachute use, the aircraft weight had to be reduced before the system was activated. This was done by severing the wings and tail section of the aircraft and then deploying the parachute package. Operational diagrams of these systems are shown in Figures 2.2 and 2.3.

Interior survival improvements were directed toward energy absorbing seat designs, improved occupant restraint systems, and the removal of sharp, hard, or loose objects which could cause injury to the passenger on impact. Stencel's seat design guideline contained the following list of objectives:

1) Minimize seat mass, particularly in the upper parts of the seat to reduce impact acceleration forces.
2) Avoid the exposure of hard structures where body impact may occur.
3) Use ductile, energy absorbing materials for primary seat structure.
4) Provide exo-skeletal seat structure for occupant protection.
5) Provide crushable impact attenuating surfaces.

Aircraft Emergency Methods

METHOD	TAKE - OFF: GROUND RUN UP TO 50ft. ALTITUDE					IN - FLIGHT: CLIMB, CRUISE, DESCENT AND APPROACH					LANDING: BELOW 50ft. ALTITUDE TO LANDING ROLL				
	G	C	M	H	E	G	C	M	H	E	G	C	M	H	E
DROGUE PARACHUTE	●	●	●		●						●	●	●		●
DESCENT PARACHUTE						●	●		●	●					
RETRO - ROCKETS (Near GRD)							●		●	●					
RETRO + STABILIZER CHUTE							●	●	●	●					
SEAT EJECTION			●			●		●					●		
CAPSULE SEPARATION			●		●			●	●	●			●		●
PERSONAL PARACHUTES						●		●							
FUSELAGE ATTENUATORS	●			●							●			●	
CRASH BARRIERS		●	●									●	●		
INTERIOR CRASH PROOFING	●	●	●	●	●						●	●	●	●	●
CRASH CAPSULES					●										●
FULL BODY RESTRAINT	●	●	●	●	●	●		●	●		●	●	●	●	●
ENERGY ABSORBING SEAT	●	●	●	●	●						●	●	●	●	●

C = Commercial Air Carrier
E = Executive Officials
G = General Aviation

H = Helicopters
M = Military Aircraft

Figure 2.1 – Emergency Methods

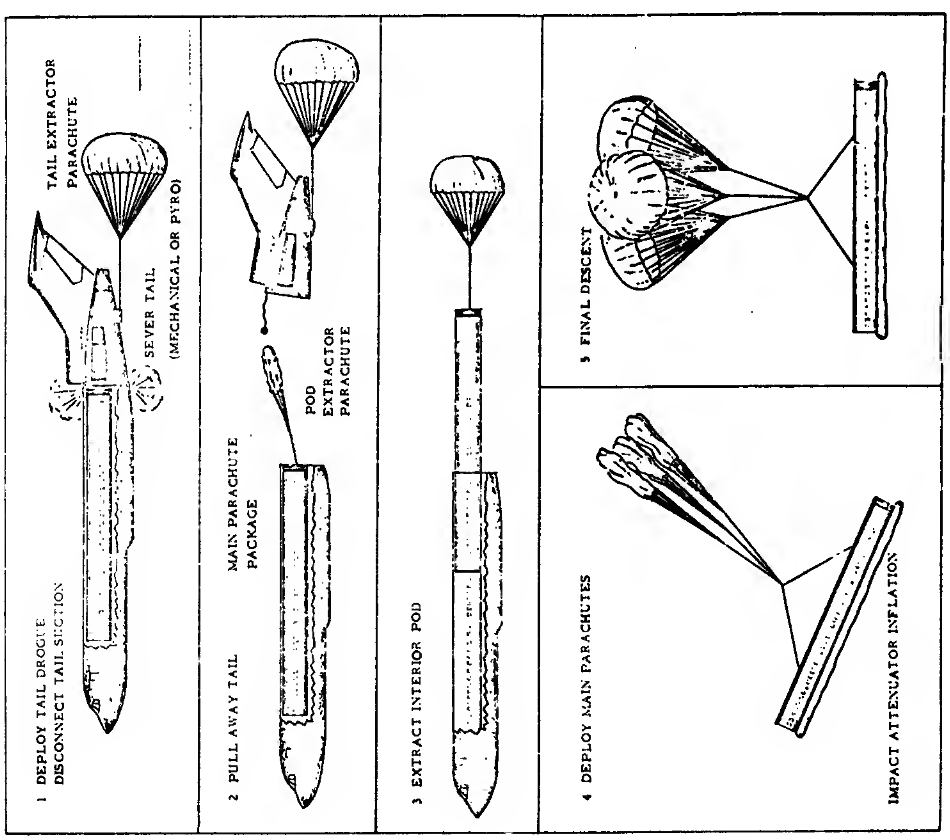


Figure 2.2 - Pod Recovery

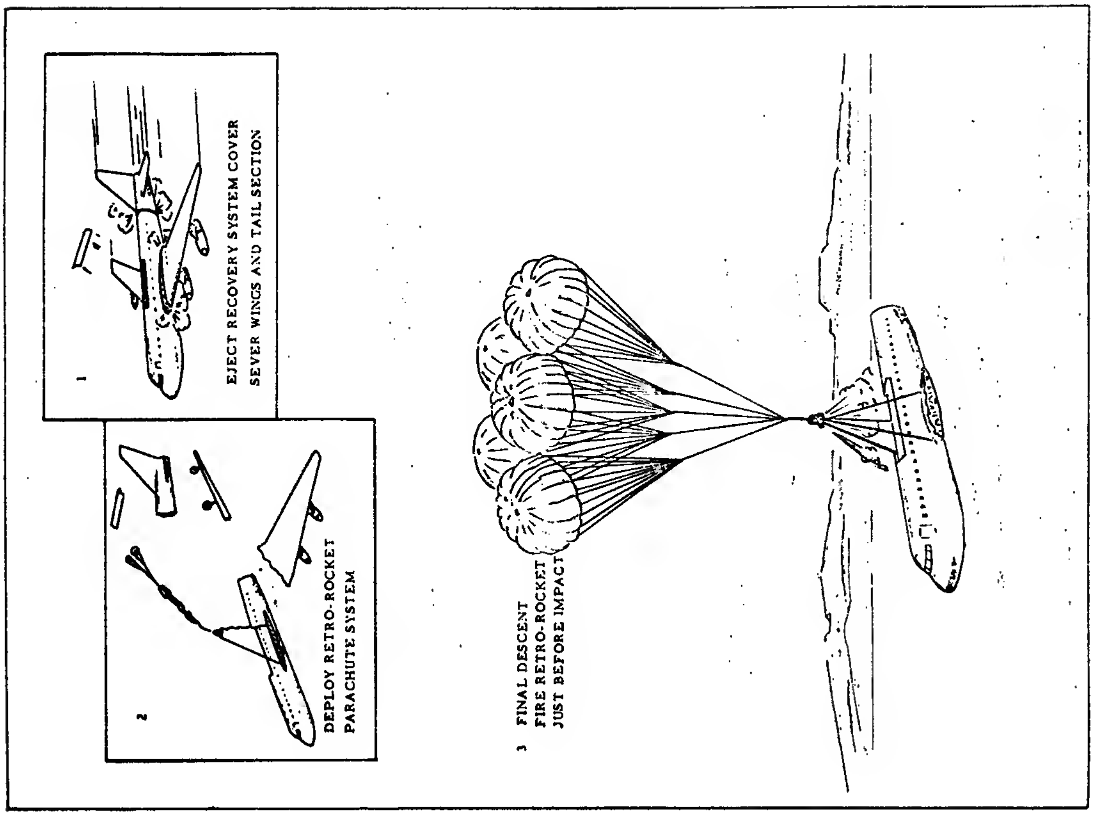


Figure 2.3 - Fuselage Recovery

6) Increase floor attachment joint flexibility to reduce bending stress.
7) Build in seat safety aids against smoke, fumes, heat and decompression.
8) Extend upper seat back above the head level for head protection.
9) Improve belt latch resistance against accidental release.
10) Provide restraint devices for upper torso and head in severe emergencies.

The basic conceptual ideas which evolved out of this guideline are shown in Figure 2.4. Compared with the standard rigid aircraft seat, the new design contained a high back protective head rest, an impact absorbing back structure, high energy dissipation cushions, high energy dissipation (stroking) load limiting legs, and a full body restraint system. Included in Figure 2.4 is the amount of expected energy absorption improvement over existing type seats. Two modifications on various aspects of the basic improved design are shown in Figures 2.5 and 2.6. In all cases, the seats were designed for impact attenuation of 20 g's vertically, 20 g's within a 30 degree arc to either side, and 10 g's laterally, based on a 225 lb. occupant weight. Stencel's previous research had indicated that there was no point in trying to design seats for attenuation of greater than 25 g's since the human tolerance at this acceleration level was extremely low.

Stencel's conceptual design program was concluded, and in February of 1968, a preliminary report was forwarded to the Biotechnology Section of NASA Headquarters in Washington, D. C., for approval and for authorization to continue the contract and build two prototype seats. After studying the report, NASA officials decided that the means described for external aircraft velocity reduction, although technically feasible, would not be acceptable to the general public. In particular, it was felt that the idea of jettisoning large parts of the aircraft in flight would be more of a deterrent than inducement to air travel. There was also some doubt as to what would happen should the system activate accidently. In view of these concerns, Stencel was notified to delete this part of the study from the report and concentrate entirely on internal survival improvements.

3. DEVELOPMENT OF AN AIRCRAFT SEAT

Initial Design

Later that year, the project was given Congressional authorization to proceed with the development of an improved airline passenger seat. NASA assigned the project to Ames Research Center in Mountain View, California.

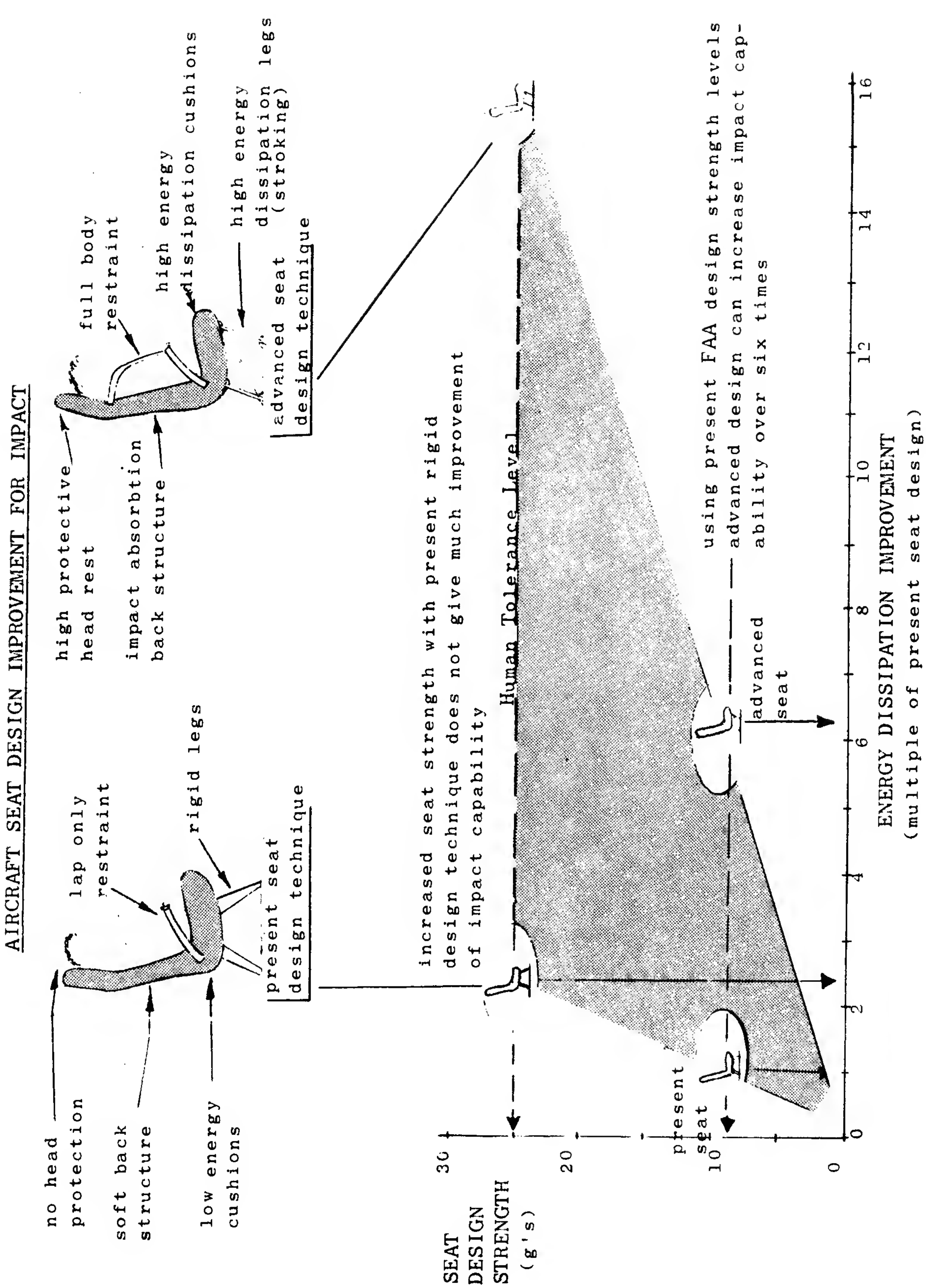


Figure 2.4 - Conceptual Design

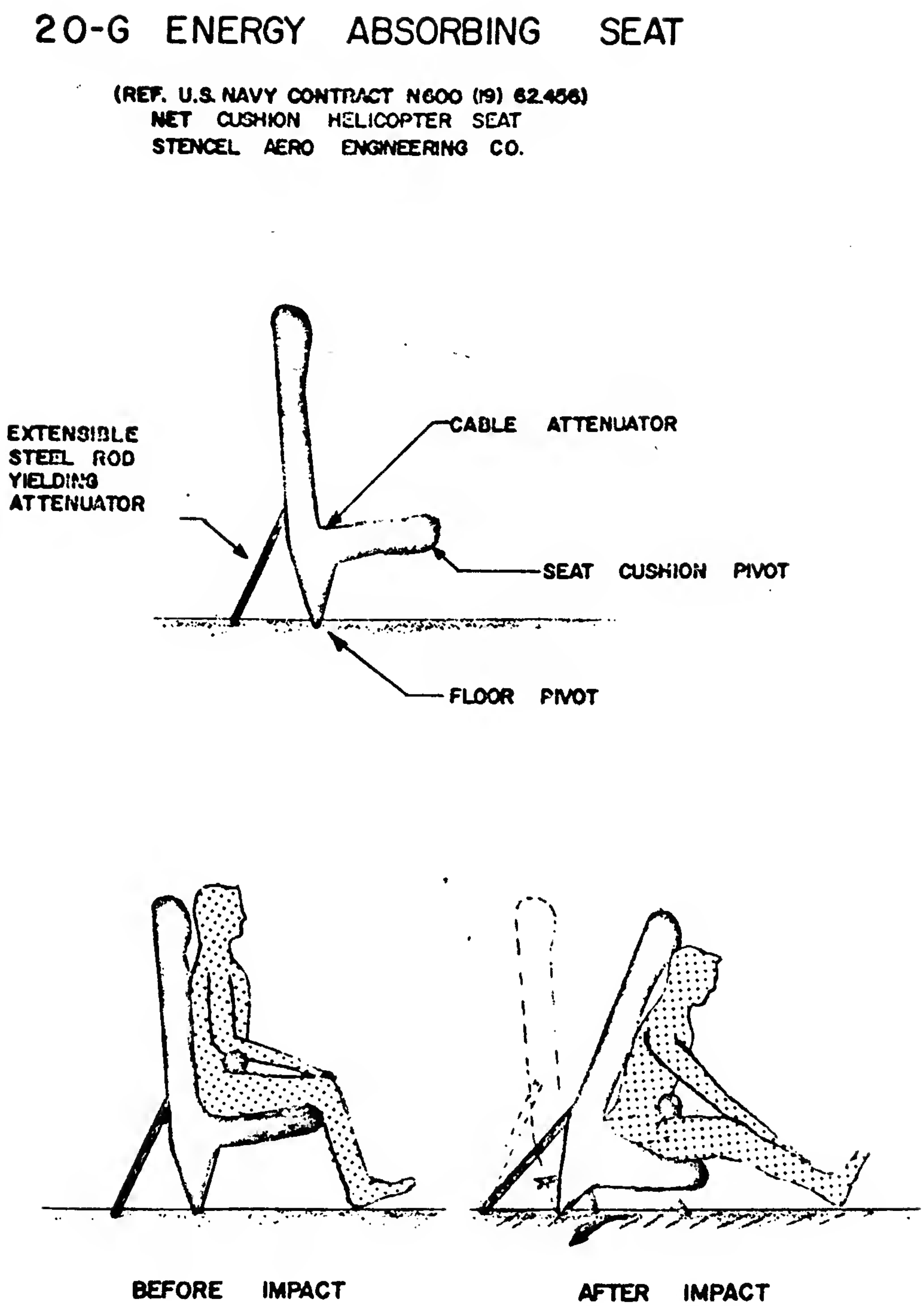


Figure 2.5 - Modification of the Design

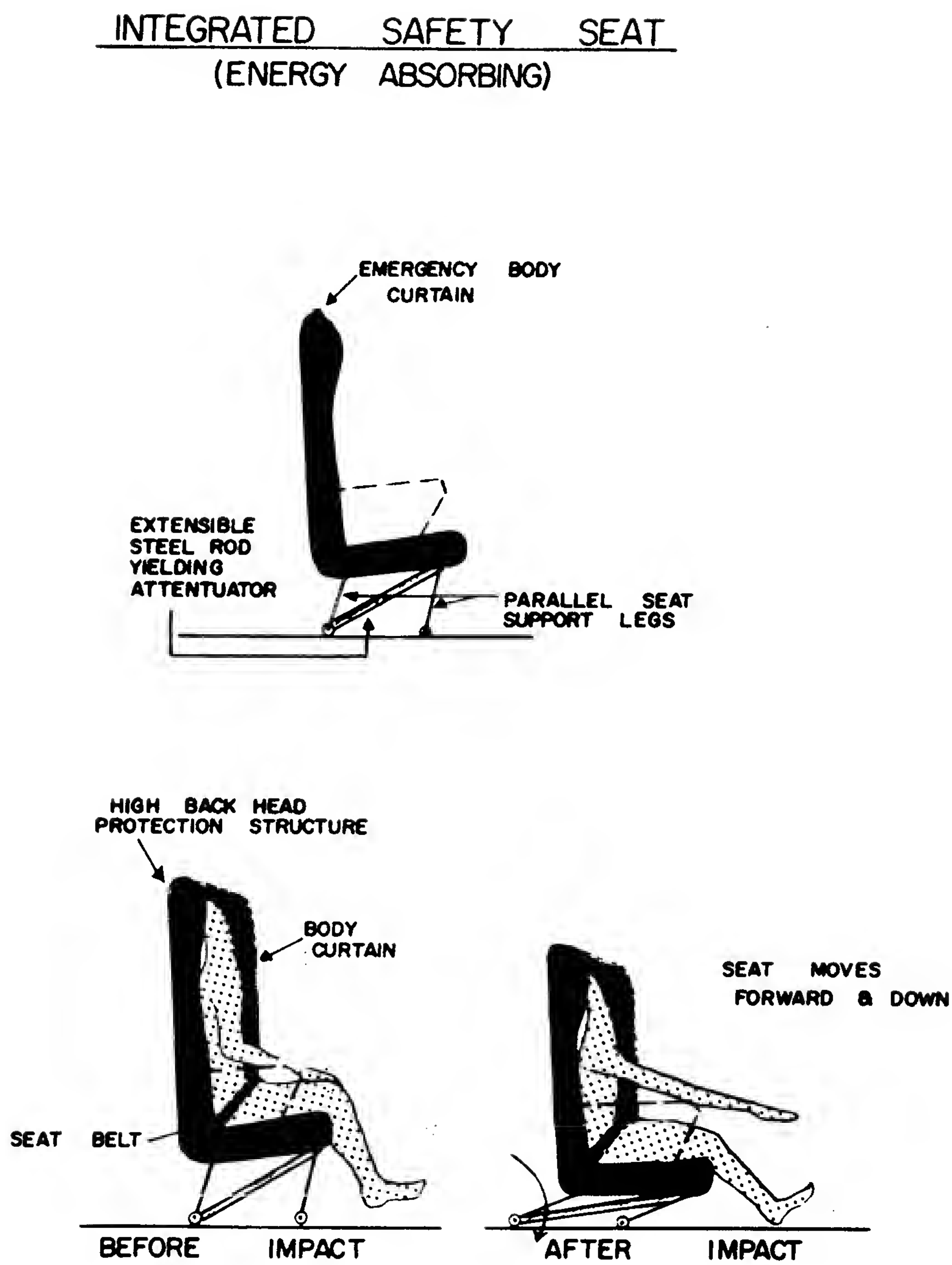


Figure 2.6 - Another Modification of the Design

At Ames Center, on 28 August 1968, Mr. Charles C. Kubokawa was appointed to oversee the remainder of the project. Mr. Kubokawa has been working in the field of human factors engineering for a number of years after receiving a bachelor's degree in psychology from the University of California, Los Angeles in 1957. He did some graduate study in psychology at the University of California, Berkeley, and later took some engineering courses while working for Philco-Ford. After he started work on this project, Mr. Kubokawa attended the Government Agency Seating Systems Conference annually to discuss current ideas and problems in the design of aircraft seats.

On 13 January 1969, Mr. Kubokawa met with Mr. Charles Yost and Mr. Ronald Oates of Stencel to discuss the future of the project. Before the project was given to Ames Research Center, Stencel had sub-contracted with two other companies, Herman Miller Corporation and Frost Engineering Company, who also had representatives at the meeting. Herman Miller Research Corporation of Ann Arbor, Michigan is a manufacturer of office furniture. They were to supply an exterior design for the seat. Frost Engineering Company of Englewood, Colorado, manufactures foam cushioning material. They were to supply a newly developed foam for the seat.

Mr. Kubokawa gave the representatives a list of things which he thought were important and which were to be included in the design.

Design Features

a) Elimination of the tray area from the back of the seat.
b) Use of shoulder straps with the lap belt.
c) Fixed exoskeleton of the seat with a movable inner seat.
d) Use of the space beneath the seat for storage.
e) Food tray to come out between arm rests.
f) Seat control, light control, volume control, call button, ventilation control, etc., all to be located in the hand area of the right armrest.
g) Vertical extension of the sides of the seats.
h) Incorporation of dual speakers on both sides of the seat.
i) Reading lights on both sides of the seat.
j) Allowance for passenger privacy and comfort.

Design Constraints

a) Total seat weight must not exceed present aircraft seat weight.
b) Seat cushions and fabric must be nonflammable.

c) Seat must be able to withstand a 12 g impact.
d) Seat must be lowered slightly in height at the base.
e) Seat must be easily removable and replaceable (for temporary conversion to freight aircraft).
f) Seat must be designed for easy maintenance.
g) Seat must give maximum protection from flying objects during an impact.
h) Seat must be designed so that it can be adapted to different modes of transportation.
i) Seat width should reflect dimensions of seats now being planned for newly designed aircraft.

At the meeting, Herman Miller Research Corporation presented two sketches of exterior design of aircraft seats to Mr. Kubokawa. Both versions were rejected because they could not accommodate an extremely tall person (above 97.5 percentile). The seats were, however, thoroughly discussed and the designers were directed to retain certain aspects in future models.

Frost Engineering Company presented a new type of memory foam at the meeting. It was rejected because, upon combustion, it gave off a toxic gas in small quantities.

The group also added four other requirements for the seat:

1) There must be provisions for different floor slopes (e.g., for SST there were 3 different floor slopes) of the aircraft.
2) There must be strong floor attachment points to which the seat might be easily installed or from which removal would be easy.
3) Consideration should be given to a shoulder strap system using inertia reels.
4) The passenger's center of mass should be below the leading edge of the seat during takeoff and landing.

Soon after the meeting, Herman Miller Corporation and Frost Engineering Company were released from their subcontracts.

Stencel designed a seat which was presented for testing in June 1970. Much of the information used in the seat design was found in the "Crash Survival Design Guide," a handbook put together by Dynamic Science under the auspices of the U. S. Army. The seat was tested at facilities of Dynamic Science in Phoenix, Arizona.

The seat was made of two major parts. The inner seat bucket, constructed of aluminum honeycomb, supports the passenger, the occupant restraint harness, and the back and bottom cushions. The bottom cushion acted as an energy absorber during crashes. The inner seat bucket was attached to an outer seat shell by a system of energy absorbing cables which elongate under a load to reduce the acceleration of the occupant in a crash situation. The outer shell was made of aluminum-urethane foam sandwich material and provided hard-points for attachment of the energy absorbing (EA) cables. The outer shell contained a food tray, ash tray, lights, and speakers for the built-in audio system. The outer part also provided the attachment mechanism to the floor of the aircraft. Figures 3.1 to 3.4 show the configuration of the seat as it was finally built.

The restraint system for the seat consisted of a conventional lap belt with two shoulder straps as seen in Figure 3.5. All belts were made of dacron and each had a breaking strength of 6,500 lbs. The lap belt had a metal-to-metal buckle and was automatically adjusted by a retracting inertial reel which locked with a 3/4 g acceleration. The shoulder harness also retracted automatically and locked with 2 g to 3 g acceleration. The lap belt was fastened so that the angle between the belt centerline and the undeflected bottom seat cushion was 53° for the fifth percentile person and 47° for the 97th percentile person. This had been found to be a good range of angles to prevent the occupant from sliding under the belt on impact.

The EA system provided a means of attenuating accelerations in the vertical and horizontal directions by allowing the inner seat bucket and occupant to move at a controlled rate with respect to the outer seat. This controlled displacement was accomplished by elongation of type 304 stainless steel cables like those shown in Figure 3.4. Two separate pairs of cables were used, each capable of elongating 45 to 47 percent of their original length.

Each of the upper pair of energy absorbers was a doubled length of 1 x 10 x 3/32" cable having an effective length of 14.25 inches. This system attenuated vertical accelerations and was positioned by a hydraulic cylinder when the seat was reclined. Figure 3.6 shows a schematic view of the upper EA system.

Figure 3.7 shows the configuration of the lower EA system, which attenuated horizontal accelerations. The cables, one on each side of the inner bucket, were single strands of 1 x 19 x 1/8" cable.

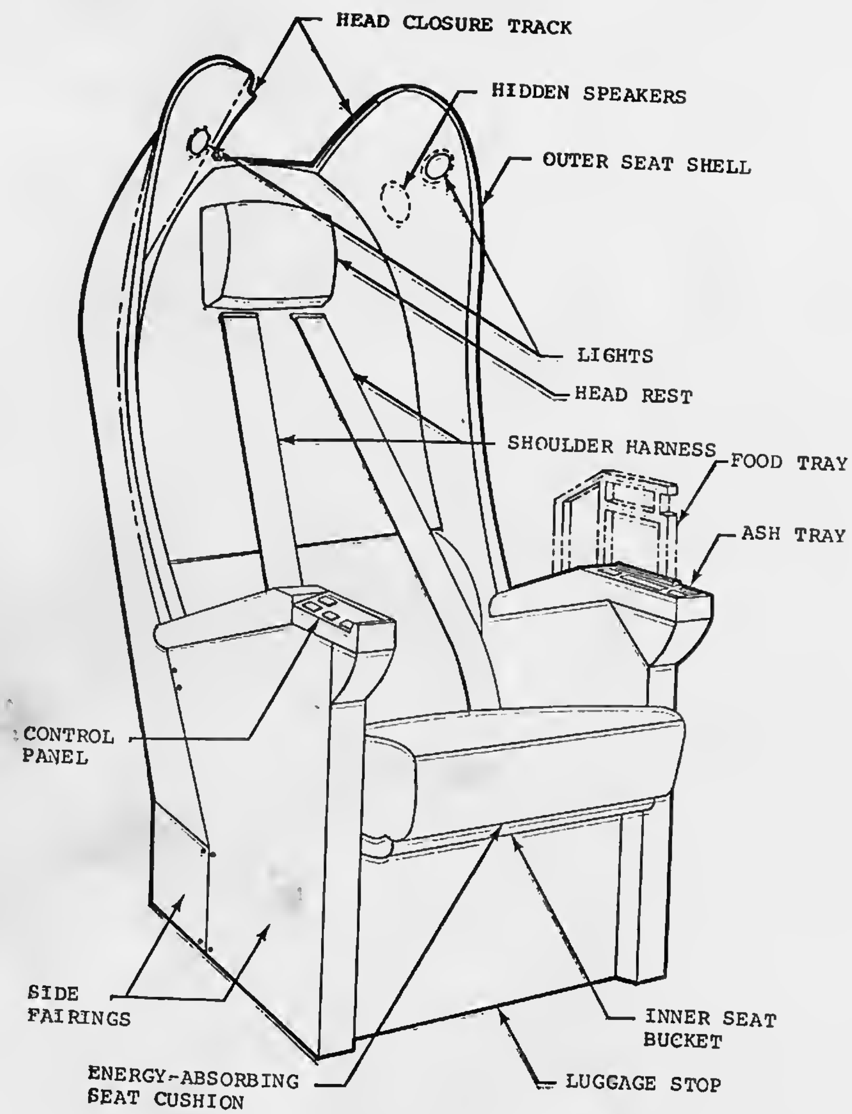


Figure 3.1 - Schematic of Seat

Figure 3.2 - Front View of Seat

Figure 3.3 - Side View of Seat

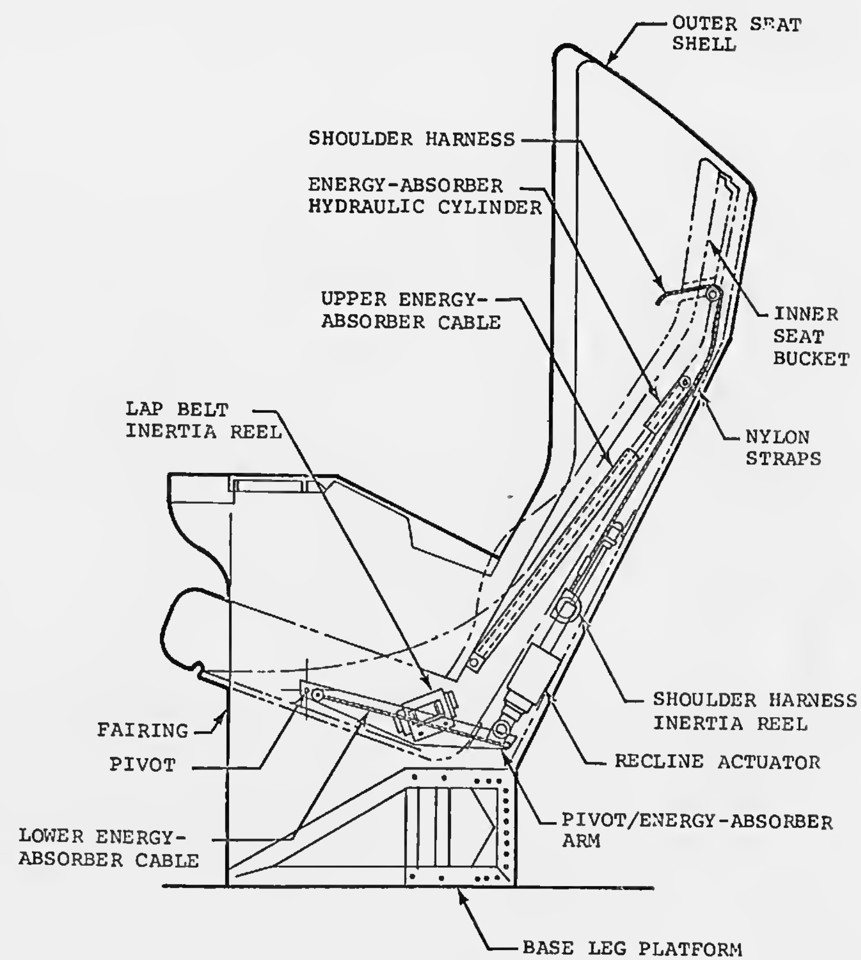


Figure 3.4 - Schematic Side View of the Seat

Figure 3.5 - Restraint System

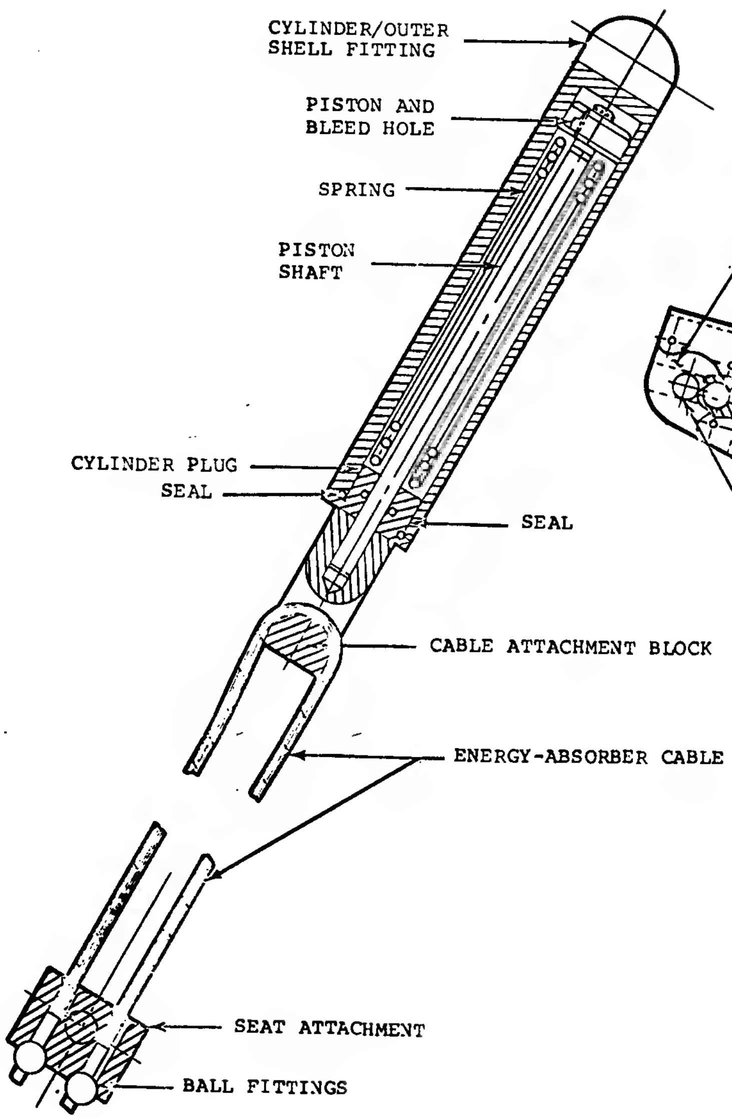


Figure 3.6 - Upper Energy Absorber Detail

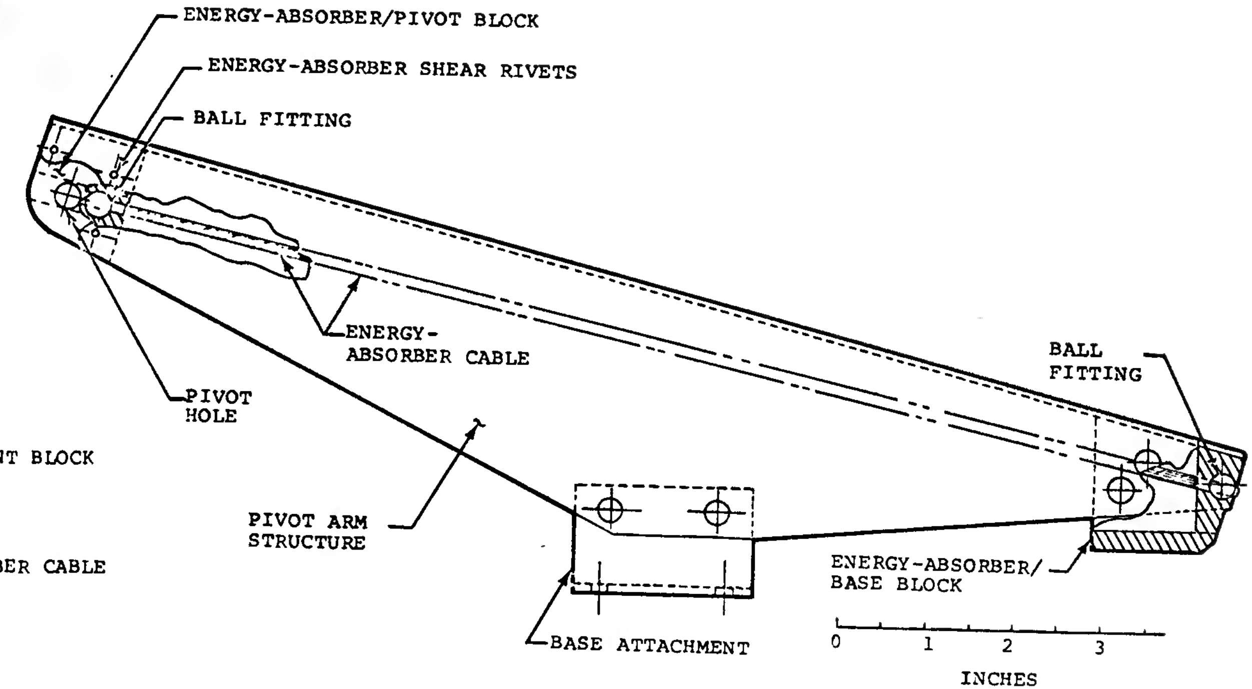


Figure 3.7 - Lower Energy Absorber Detail

The bottom seat cushion had a lower layer of viscous, minimum rebound foam and an upper layer of soft foam for comfort. It acted as a critically damped material and therefore absorbed considerable energy upon impact. The seat cushions are shown in Figure 3.8.

The EA system functioned under large dynamic loads. When a force of 1,000 lbs. was applied to the seat along the longitudinal or vertical axis, the shear rivets in the front pivot block on the lower EA system would fail. If the loading was continued, the connection between the recline actuator and the inner seat would also shear at 1,000 lbs., releasing the inner seat. The inner seat would then move until its kinetic energy had been absorbed by elongation of the cables. Should a large moment be acting on the seat, the inner bucket would be restrained from tipping too far forward by two pattern-stitched nylon strap stitch breaker systems which limited the travel of the upper end of the inner seat.

In order to make the seat acceptable for commercial use, a number of passenger convenience systems were added. These included reading lights, an ash tray, a food tray, a built-in audio system, and an electro-mechanically powered seat-recline actuator. The controls for these systems were built into a panel on the right armrest as shown in Figure 3.9. The panel also housed a stewardess call button and "No Smoking" and "Fasten Seat Belt" signs.

First Tests

Testing of the seats was conducted by Dynamic Science, a division of Marshall Industries, in Phoenix, Arizona. Mr. Jim Jones represented NASA at the test, as Mr. Kubokawa was busy on another project. The tests included static and dynamic tests in the vertical and horizontal directions.

The seats weighed 91.5 lbs. each. To obtain good photographic coverage of the tests, the side fairings and food tray were removed, reducing the test weight to 82.3 lbs.

The static test caused a failure of the EA cables at 2,300 lbs. in the horizontal direction. In the vertical direction, the seat withstood a 4,650 lb. static load without damage.

Figure 3.10 shows the test facilities for the dynamic tests. Table 1 shows the results of the dynamic tests. Tests 1 through 7 were vertical tests. The seat survived these tests without major problems. Tests 8 and 8A were longitudinal tests. In test 8, the tie-down mechanism for the seat failed. This was redesigned and test 8A was begun. In test 8A the seat experienced a compression failure at the forward edge of

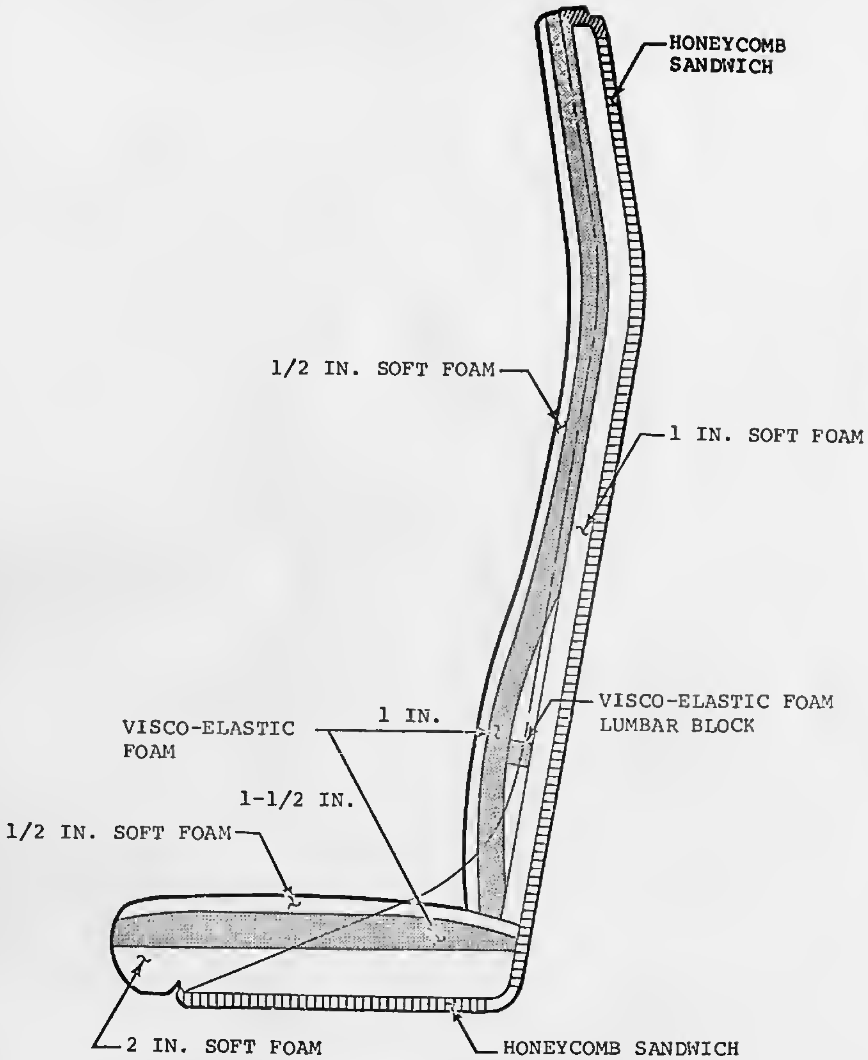


Figure 3.8 - Inner Seat Cushion Construction

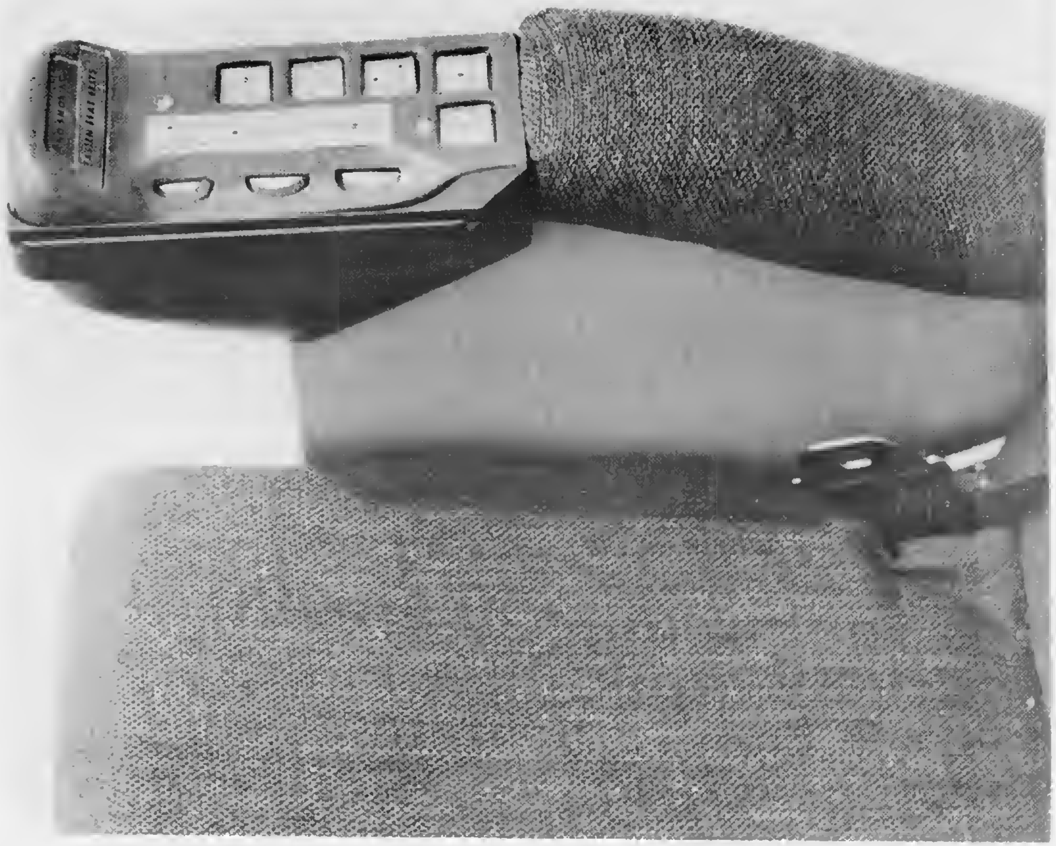


Figure 3.9 - Control Panel for Convenience Systems

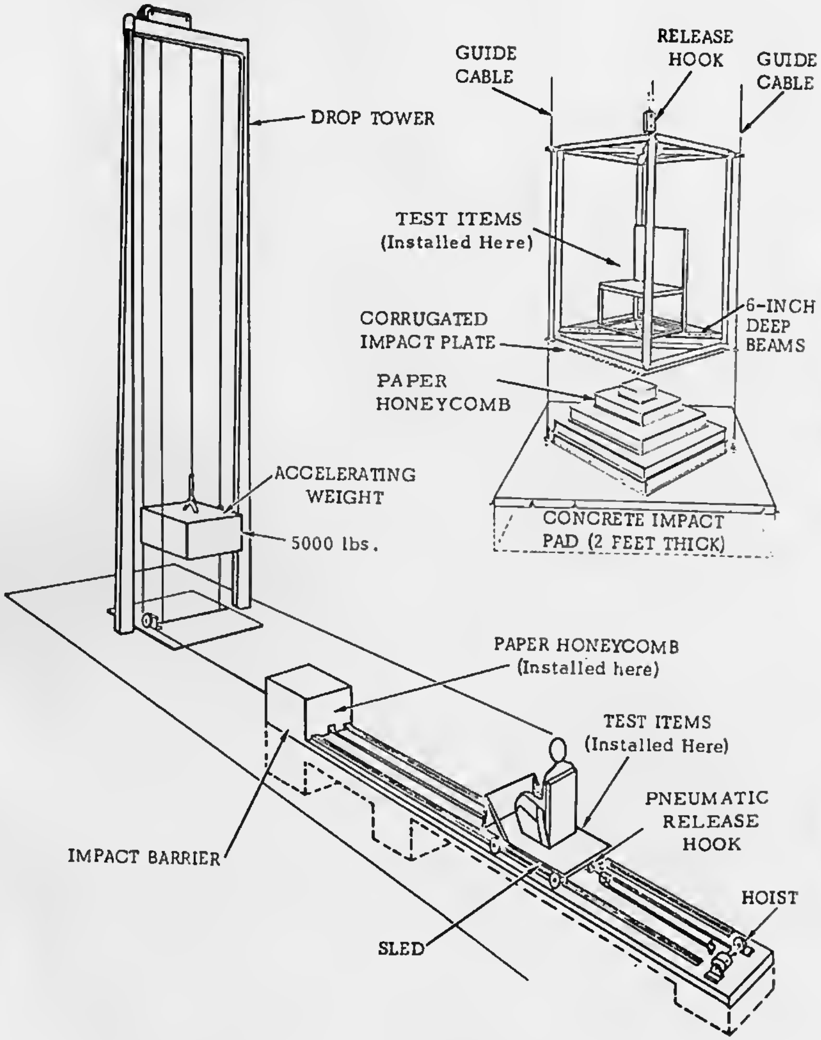


Figure 3.10 - Drop Tower and Longitudinal Accelerator Test Facility

Figure 3.11 - Close-up of Compression Failure of Right Side of Outer Shell Test 8A

TABLE 1
Summary Results of Dynamic Tests

Measurement	Test 1	2	3	4	5	6	7	8	8A
Input Acceleration - G	10.9	17.5	21.3	14.3	15.5	13.0	19.2	8.1	7.6
Velocity Change - ft/sec	28.5	31.4	29.6	36.9	41.8	44.6	22.6	25.5	24.2
Seat Pan Acceleration -									
Vertical - G	9.5	34.6	50.0	35.5	22.0	13.0	47.5	N/A	N/A
Longitudinal - G	N/A	N/A	N/A	N/A	N/A	N/A	N/A	9.3	12.7
Occupant Pelvic Acceleration -									
Vertical - G	9.3	20.0	30.0	18.8	13.0	11.4	23.8	N/A	N/A
Longitudinal - G	N/A	N/A	N/A	N/A	N/A	N/A	N/A	10.7	11.7
Seat Loads - Vertical - lbs.									
Left Rear	-1320	-1860	-3100	-2500	-2540	-1540	-2630	+1230	+2660
Right Rear	-1580	-2450	-4160	-2340	-2410	-2000	-2360	+2640	+2430
Left Front	- 600	- 760	+ 440	- 380	- 420	- 230	- 270	-1440	-2250
Right Front	- 410	- 480	+ 590	- 200	- 310	- 200	- 210	-2717	-2490
Energy Absorber Stroke - Inches									
Vertical	0	1	1.5	1	1.5	0	1	0.5	1
Longitudinal	0	0	0	0	0	0	0	0.5	0.5

TABLE 2
Six Phases of Development

	Project	Contract #	Date	Report	Scope
1.	Project taken over from NASA Headquarters	NASw 1530 (ARC H. Vykukal) Stencel Aero Engineering	2/28/68	Final Engineering Study Report	Human Survival in Aircraft emergency (a) Passenger protection through seating and occupant restraint design (b) aircraft velocity reduction before impact by devices deployed from a/c.
2.	First ARC directed contractual effort	NAS2-5101 (ARC C. Kubokawa) Stencel Aero Eng. (R-3883)	8/28/68	4 Quarterly Reports	Design and development of NASA Integral Passenger Seating. (1 functional mockup).
3.	Contract Extension	NAS2-5101 (ARC C. Kubokawa) Stencel Aero Eng. (R-3883)	12/31/69	Study of Seat Design for Human Survival in a/c emergencies	Fabrication of 2 operational seats for dynamic testing to 20 g's and 1 operational prototype model.
4.	Contract Overrun	NAS2-5101 (R-3883)	2/9/70	-	Increased costs.
5.	Crashworthy test and evaluation of an experimental a/c seat	NAS2-5867 (Dynamic Science AVSER Facilities)	3/31/70	Interim report	Dynamic seat testing of two seats
6.	Contract Overrun	NAS2-5101 (R-4536) Stencel Aero Eng.	9/11/70	-	Increased Costs
7.	Proposal for contract extension	NAS2-5101 Stencel Aero Eng.	10/20/70	-	Fabrication of 4 basic seat structures for dynamic testing and one operational seat for helicopter installation.

the outer seat as shown in Figure 3.11.

The report on the seat from Dynamic Science contained the following conclusions from the testing:

1) The seat has many desirable and worthwhile features relative to comfort, appearance, convenience, and ease of operation.
2) The powered actuator caused the system to be rather complex. The power consumed during mass usage on an aircraft would be undesirable. Also, the noise level of the actuator is too high.
3) The seat is more crashworthy in the vertical direction than those presently in use in commercial aircraft.
4) The seat is structurally adequate for vertical loading, but the EA system must be improved to limit the occupant loading.
5) The seat was not structurally adequate in the horizontal direction.
6) Two seats were inadequate for performing reliable tests.

The report also contained a set of recommendations:

1) Additional dynamic analysis should be performed in the vertical direction to improve energy absorption.
2) The inner seat should be able to stroke a full six inches without interference from other parts.
3) The outer seat should be redesigned and additional longitudinal dynamic analyses should be made.
4) The nylon straps for limiting travel should be replaced by an EA device.
5) A more adequate test plan should be constructed including the longitudinal, lateral, and vertical axes in the testing.

The project, since it was assigned to Ames Research Center, had now gone through six phases of development as shown in Table 2.

<u>Redesign</u>

It was decided at NASA Headquarters that the failure of the seat indicated a need for a backup program. Dennis Matsuhiro, an employee of the U. S. Army on loan to the NASA Ames Engineering Group, was assigned the task of designing a second seat which would be developed in parallel with the Stencel seat. The design was to be as independent as possible in an effort to detect and avoid future problems.

Mr. Matsuhiro, a graduate in Mechanical Engineering at Oregon State University, proceeded to do a literature search on the different systems involved in the design of the seat. At the same time, Stencel initiated several redesign programs including revision of the outer shell structure, inner seat, recline actuator, EA cables and the restraint system.

During the first testing program at Dynamics Science, high accelerations ("overshoot") were being experienced by the dummy. Two of the above changes were made in an effort to avoid the problem. A two-inch honeycomb sandwich was added to the seat pan to increase the structural integrity during dynamic loading. The seat cushion was correspondingly reduced in thickness and made firmer, in an effort to reduce the acceleration overshoot problem.

The EA system was modified by preloading and lengthening the cables. The pretensioning, like the firmer seat cushion, was intended to reduce the overshoot problem. The cables were increased in length to increase the stroking distance during loading.

The outer shell structure was redesigned with emphasis on structural integrity. Rather than the solid sheet metal frame, a truss design, shown in Figure 3.12, was adopted which resulted in a strong, light frame capable of withstanding the large compression forces generated by the horizontal accelerations. Preliminary tests on the truss structure indicated a minimum load capacity of 5,600 lbs. greater than a 20 g horizontal load input.

The mechanism used for placing the seat in the recline position was changed from the original electro-mechanical system to a pair of spring-loaded hydraulic pistons, as shown in Figure 3.13. This was done in an effort to decrease the weight and cost of the seat. A force of approximately 100 lbs. would be required to force the seat into the recline position and the spring would return the seat to its original position upon opening of a valve.

Stencel also made slight modifications on the restraint system. Mr. Matsuhiro, however, had developed a superior seat belt system, shown in Figure 3.14, while designing the parallel seat. This improved system was employed for the second test.

Second Testing

By 27 October 1971, the redesigned Stencel seats (two identical seats were made for the testing program) were ready for testing. Arrangements were made to perform the dynamic

Figure 3.12 - Truss Design

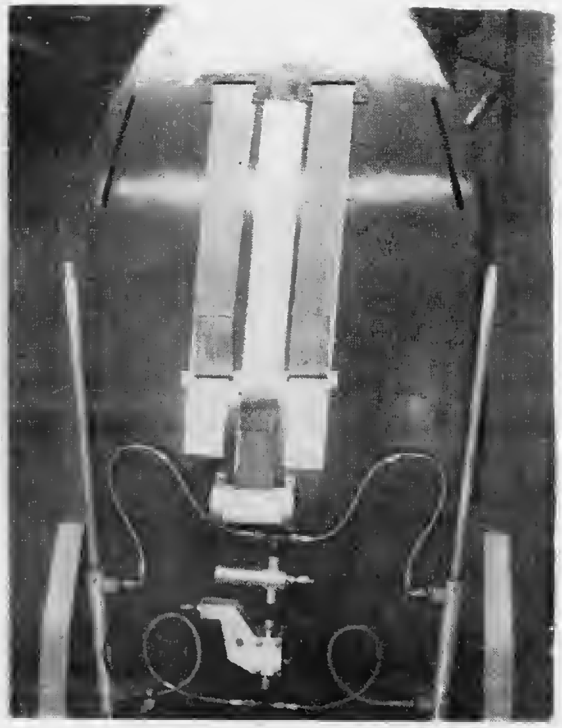


Figure 3.13 - Hydraulic Recline Mechanism

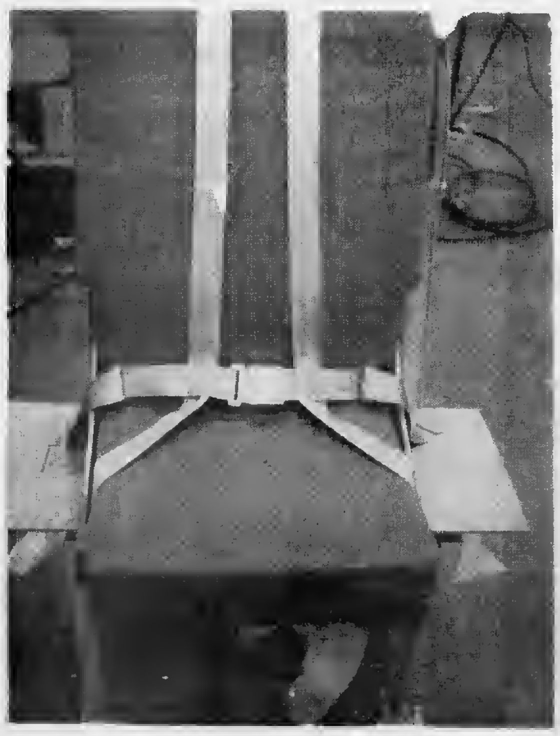


Figure 3.14 - Improved Seat Belt System

impact tests at the Civil Aeromedical Institute (CAMI) which are facilities operated by the FAA at Oklahoma City, Oklahoma. These tests were designed to determine both the horizontal and vertical load capacities.

Attending the tests were Charles Kubokawa and Dennis Matsuhiro. They refurbished the seats after each test run (some components, such as the EA cables, are designed to fail in a controlled manner) and interpreted the test results.

Early in the horizontal testing, poor fabrication of the seats resulted in a failure (Exhibit 1). After repairs, satisfactory results were obtained in the horizontal direction. The vertical testing, however, indicated extremely large peak accelerations as experienced by the dummy. It was felt that there were two possible causes for this problem. First, the dummy being used did not adequately simulate the dynamics of a human body and second, the slider block system (an aluminum guide rail and sliding block used for controlling the motion of the inner seat with respect to the outer seat) may have been restrained from sliding freely as it was designed to do. Because of these problems, the vertical portion of the test was considered a failure. The horizontal testing, however, had surpassed the 21 g level and thus was considered a success.

Immediately following the testing at Oklahoma, Mr. Kubokawa presented the results to the Government Agency Seating Systems Conference. The panel seemed interested, and encouraged further development. There was even some mention of installing a few operational models in the Presidential helicopter.

Second Redesign

Following the tests, two modifications were made. First, the U. S. Air Force dummy, called Dynamic Dan, was obtained for subsequent testing. Dan is water filled and more closely approximates the dynamics of a human. Second, the slider block was modified in an effort to prevent its gouging problem. It was felt that the slider block was digging into the guide rails rather than sliding. If this were the case, the high peak accelerations could easily be accounted for. To solve the problem, the corners and edges of the block were rounded.

Third Testing

By 22 March 1972, all modifications had been made and again the seats were ready for testing. Rather than spend the time and money to retest the seats in the horizontal direction, it was assumed that they had qualified in that direction from the first test at Oklahoma. Attention was thus focused on vertical testing.

Charles Kubokawa and Dennis Matsuhiro attended the testing. Once again their purpose was to supervise the testing, refurbish the seats, and interpret the data.

On the first run of the testing, a failure occurred (see Exhibit 3.2). Immediate inspection showed that the wrong size bolts had been used to attach the roller guide block to the seat. The mistake was a result of fabrication and not of design. The error resulted in the bolts being sheared off when subjected to the large load.

The tests were resumed the next day after the proper bolts had been installed. Further testing resulted in satisfactory data for g levels up to 45 g's in the vertical direction.

4. DEVELOPMENT OF PARALLEL SEAT

During this same period, Mr. Matsuhiro was working with his own design. Late in September, 1971, Mr. Matsuhiro finished a set of detailed drawings of his own seat concept. These drawings were given to the NASA Ames machine shop where an estimation of the cost for building a prototype was to be made. Mr. Matsuhiro anticipated design changes in the near future after the first test at Oklahoma, so he did not pursue the cost proposal during the month preceding the test.

After the second test results were known, Mr. Matsuhiro decided he should pursue the cost evaluation of his own seat design. Not having heard from the shop for the preceding month he confronted the shop personnel to find that they had misplaced the drawings. For the following two months the shop searched for the drawings. Once they had been located, Mr. Matsuhiro began to arrange to have the prototype made. Unfortunately, the $50,000 allocated for his program had been reallocated to another project because Mr. Matsuhiro was unable to get a cost estimate for the seat from the shop. It was therefore decided to focus attention upon successfully completing the Stencel seat.

5. FUTURE DEVELOPMENT

The final test completed Stencel's contract obligations. NASA officials decided not to renew the contract with Stencel, but rather to carry on further development "in house" (at Ames Research Center). The present seat design is shown in Figure 5.1.

The further development which is necessary involves modification of the recline actuator system, lightening of the seat as

Figure 5.1

The Final Design

a whole and improving the attenuating characteristics at low g levels.

Once again, however, skepticism has arisen at NASA Headquarters. The question now becomes one of determining whether future development is justifiable. Apparently the lack of push from the benefactors involved (airlines, public, etc.) has been the cause of the hesitancy in Washington. As a result, Mr. Kubokawa must now contact the airlines in an effort to gain support for his program. Two alternatives face him during this campaign. He may either arouse enough support from the airlines or he may convince the FAA that such a seat is necessary for safety in commercial airlines.

If Mr. Kubokawa's efforts fail to gain the financial backing for the coming year, the seat will die as a prototype. The only hope would then be that some company would pick up the NASA design and complete the development. According to Mr. Kubokawa, it may be that we are several catastrophic airline accidents away from a safer NASA seat.

NASA-Ames LTI:239-3
Moffett Field, California
December 21, 1971

MEMORANDUM for Director

From: C. C. Kubokawa, Research Scientist

Subject: Trip report to FAA, Civil Aeromedical Institute (CAMI) November 30 to December 7, 1971, Oklahoma City, Oklahoma

The subject trip was taken for two reasons:

1) To conduct dynamic impact tests on the NASA-Ames Integral Commercial Aircraft Passenger Seat (Dec. 1 - Dec. 7)
2) To participate in the U.S. Government Agencies seating panel (Dec. 1 and 2)

As part of the government seating conference, the dynamic impact testing of the NASA seat was shown to the attendees. The list of personnel attending the seat conference is submitted as Attachment 1.

The attendees were quite pleased to see the dynamic testing of the ARC seat, and they encouraged the NASA to continue the seat project to completion, certification and ultimately commercial use.

Mr. F. Castellion (FAA Washington, D.C.) stated that he would provide help in getting the seat certified if the writer did not have the proper contacts in Washington.

Mr. Paul Altman (Naval Air Systems Command, Washington) also stated that the Navy is still interested in installing a few approved operational models of the NASA seat into the presidential helicopter.

The concept of the seat was well accepted by the group. As far as the dynamic testing was concerned, the writer feels that the new structural design of the seat was a great success, in comparison to the previous seat design tested at Dynamic Science last year. The last seat structure failed at close to 11 g (horizontal), whereas, the present seat surpassed 21 g.

There were a few design and fabrication errors found in the new seat. The poor workmanship error eventually caused the failure of one of the two test seats early in the horizontal test program. A modification of the remaining seat enabled the testing of the seat to continue until reliable data were gathered.

EXHIBIT 1

Since all the slow motion movies and still pictures have not yet arrived from CAMI, we are not yet able to determine what modifications will be necessary to make the seat into a completely acceptable seat. The re-design of several minor and one major portion of the seat is envisioned as an in-house effort. The major task is in the modification of the energy absorption system in a biaxial mode.

It is recommended that further design remodification on the NASA-Ames aircraft seat be conducted in-house. The projected cost would be around 90K for two operational models, inclusive of peripheral support equipment (e.g. passenger seat control panel, lights, etc.).

At the seat conference, CAMI distributed a list of active research programs being conducted for DOT, an organizational project chart, and a list of publications on "Protection and Survival." These items are submitted herewith as Attachments 2, 3 and 4.

Mr. Dennis Matsuhiro on loan from the Army Mobility Laboratories at ARC, to the Research Equipment Engineering Branch of Ames, was responsible for the success of the seat testing operations, and without his support the test would not have been possible. His dedicated effort is fully appreciated by the Biotechnology Division.

Charles C. Kubokawa

Charles C. Kubokawa

Enclosures:
Attachments 1, 2, 3, & 4

HM
CAS
HPK
DLW
JB
MS
CKubokawa:pb 12-21-71/2551
cc:
D. Matsuhiro
A. Merkin - NASA Hqrs Code RB
L. Fox - NASA Hqrs Code RB

NASA Hqrs Code R
NASA Hqrs Code I

NASA-Ames LTI:239-3
Moffett Field, California
April 5, 1972

MEMORANDUM for Director

From: C. C. Kubokawa, Research Scientist, Man-Machine Integration Branch

Subject: Report of trip to FAA, CAMI, Oklahoma City, March 22-24, 1972

The subject trip was made by the writer and Dennis Matsuhiro to conduct a series of vertical dynamic impact tests on the NASA, Ames aircraft passenger seats.

The impact tests were conducted using both the Air Force anthropometric dummy, "Dynamic Dan" and the FAA Alderson dummy.

The one and only seat failure occurred on the very first test. The failure was attributed to a wrong size bolt, which was used to attach the roller guide blocks of the outer seat shell to the main seat structure. (3/16 inch diameter bolts were used instead of 1/4 inch bolts.)

The tests were resumed on the following day after minor modifications of the roller guide block attachment points on both test seats.

The following is a brief summary of the vertical test data:

Test #	Dummy Used	Seat Peak Loading	Seat Attenuation (1)	Comments
1	Dynamic Dan	25g	to 22.5g attenuated 2.5g	*
2	Dynamic Dan	34g	to 25g attenuated 9g	
3	Dynamic Dan	45g	to 25g attenuated 20g	@
4	Dynamic Dan	34g	to 25g attenuated 9g	
5	Dynamic Dan	33g	to 25g attenuated 8g	
6	Alderson	35g	to 25g attenuated 10g	
7	Alderson	34g	to 25g attenuated 9g	

(1) Occupant of seat experiences 4-5g less than seat g because of g attenuating cushion.

* Required repairs to roller guide blocks. Sheared off bolts of guide block. Wrong size bolts were used in initial assembly at ARC.

@ Hit 3/4 inch plywood on flooring. Almost limit of energy absorbing cable stretch length.

EXHIBIT 2

Significant data were gathered to help improve the seat design. The tests revealed that the seat structures were designed well enough to withstand and attenuate a 45g vertical drop. Seat impact g attenuation could be increased at the lower 33-35g levels if softer or smaller diameter energy absorbing cables are used.

It is felt that the tests were highly successful, and the seat program should be continued until an operational prototype seat with significantly improved crash protective properties (relative to current civil aircraft seats) is demonstrated.

C. C. Kubokawa

C. C. Kubokawa

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EXHIBIT 2